

APPLICATION OF NASA-DEVELOPED TECHNOLOGY  
TO THE AUTOMATIC CONTROL OF MUNICIPAL  
SEWAGE TREATMENT PLANTS

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NASA-DEVELOPED TECHNOLOGY TO THE AUTOMATIC  
CONTROL OF MUNICIPAL SEWAGE TREATMENT  
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by

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Prepared under Contract No. NAS 1-11726

by

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San Antonio, Texas 78284

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

November 1973

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## FOREWORD

This report was prepared at Southwest Research Institute under NASA Contract NAS 1-11726. The work was administered by NASA Langley Research Center, Hampton, Virginia 23365, with Mr. John B. Hall, Jr., serving as Technical Monitor.

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# APPLICATION OF NASA-DEVELOPED TECHNOLOGY TO THE AUTOMATIC CONTROL OF MUNICIPAL SEWAGE TREATMENT PLANTS

by

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## SUMMARY

A search was made of NASA-developed technology and commercial technology for process control sensors and instrumentation which would be applicable to the operation of municipal sewage treatment plants. Several notable items were found from which process control concepts were formulated that incorporated these items into systems to automatically operate municipal sewage treatment plants. A preliminary design of the most promising concept was developed into a process control scheme for an activated sludge treatment plant. This design included process control mechanisms for maintaining constant food to sludge mass (F/M) ratio, and for such unit processes as primary sedimentation, sludge wastage, and underflow control from the final clarifier.

## INTRODUCTION

Historically, sewage treatment plants have been built on the premise that a minimum of operating attention should be required. As a result, plant designs have incorporated minimum instrumentation and process controls. Some plant designs are such that once they are fabricated there is very little chance to add process controls. The trickling filter plant is an example of this situation. Although this approach was economically attractive and environmentally acceptable for many years, it is no longer tenable. The effluent quality from such plants in some locations is not acceptable for discharge into many of our overloaded streams and waterways. In addition, the increasing demand for reuse of municipal wastewaters requires the consistent production of a high quality effluent. In order to enhance process capability to meet these requirements, treatment plants could possibly be provided with automatic process control systems which could sense changes in process variables on a real time basis, and make compensating adjustments to the process unit.

The magnitude of this process control problem is illustrated in Figure 1. This figure is a plot of the diurnal variation in hydraulic flow rate of sewage and mass flow rate of the dissolved organics contained in the sewage at a large metropolitan sewage treatment plant. The data were taken over a three-day period to illustrate the diurnal cycle of this loading phenomenon. Several points are illustrated by this figure: (1) hydraulic flow varied over a range greater than 2 to 1, (2) the organics concentration increased with hydraulic flow which caused the actual mass flow of dissolved organics to vary over a range of greater than 6 to 1, (3) the maximum plant loadings occurred on the night shift when operating supervision and effluent monitoring were apt to be minimum, and (4) the magnitude of variations differs between sequential 24-hour periods even though a definite diurnal pattern is established. These points establish the need for process control parameters which can be determined rapidly and which are amenable to automatic control of the treatment process. In contrast to this need, most sewage treatment plants are operated without process control. This lack of control is partially attributable to the analytical methods used to describe the treatment process.

The more common process control parameters which are now used in sewage treatment plant operation are listed in Table 1. Also listed for each parameter are the approximate lag times involved between sampling and final feedback of analytical results. Five-day Biochemical Oxygen Demand ( $BOD_5$ ) is included in Table 1 even though it cannot be considered a control parameter. Of all the analyses listed in Table 1, only Dissolved Oxygen (DO) may be determined in sufficient time to allow a control adjustment to be made. The lag times of all other analyses are either longer than the retention time of the reaction vessels or are sufficiently long that process conditions will have changed before the analysis is completed.

Recognizing the need for improvement of the current methods for controlling municipal sewage treatment plants, NASA Contract NAS 1-11726 was issued to determine if NASA developed technology could be applied to this problem. The objective of this effort was to provide a preliminary design of a control subsystem using NASA-developed technology, wherever possible. To accomplish this objective, the following three work tasks were included in the contract:

- 1) a technology survey to determine state-of-the-art developments that were applicable to the process control of municipal sewage treatment plants,
- 2) conceptual designs based upon the results of the survey, and
- 3) a preliminary design of the most promising concept resulting from the conceptual design effort.



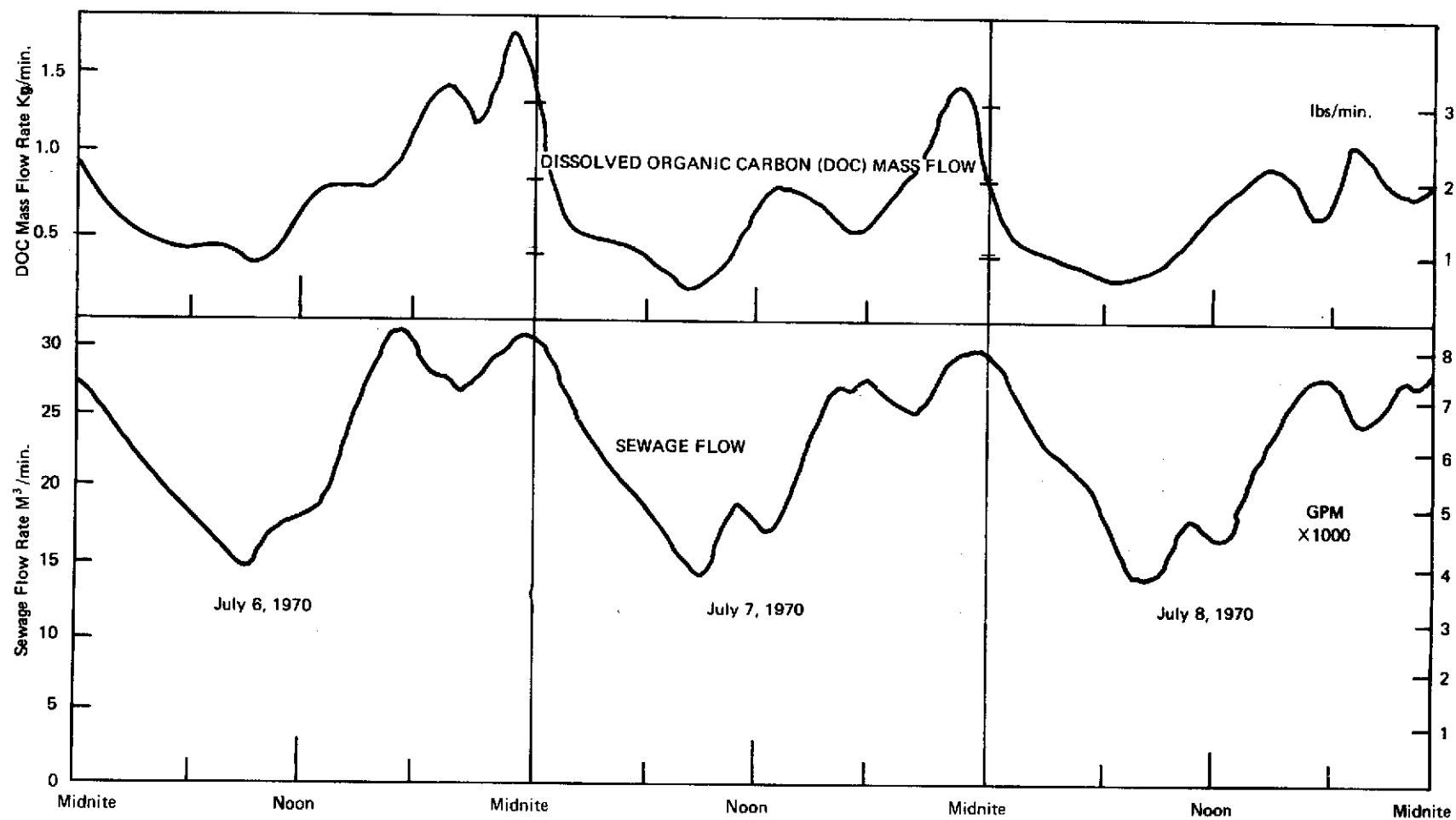


FIGURE 1. DIURNAL VARIATIONS IN FLOW AND DOC OF RAW SEWAGE AT THE LEON CREEK TREATMENT PLANT

**TABLE 1. PROCESS CONTROL PARAMETERS IN COMMON  
USE FOR ACTIVATED SLUDGE TREATMENT PLANTS**

Control Parameter	Analytical Procedure	Analytical Time
Organic Loading	Biochemical Oxygen Demand (BOD <sub>5</sub> ) Chemical Oxygen Demand (COD) Total Biological Oxygen Demand (T <sub>b</sub> OD)	5 days 3 hours 3-8 hours
Activated Sludge Mass	Mixed Liquor Suspended Solids (MLSS) Mixed Liquor Volatile Suspended Solids (MLVSS)	1-2 hours 2-3 hours
Solids Separation Characteristics	Settleable Solids (SS) Sludge Volume Index (SVI) Sludge Density Index (SDI)	1 hour 1-2 hours 1-2 hours
Aeration Rate	Dissolved Oxygen (DO)	5 min.
Effluent Quality	Biochemical Oxygen Demand (BOD <sub>5</sub> ) Chemical Oxygen Demand (COD) Nonfiltrable Residue (Suspended Matter)	5 days 3 hours 1-2 hours

## PROGRAM TASKS

### Technology Survey

NASA Technology Search. -- The NASA Technology was searched through inquiry to the NASA Scientific and Technical Information Facility (STIF) at College Park, Maryland. The NASA literature search was based on a computerized records search of the technical reports, journal articles, books, conference papers, and other publications stored in the NASA-STIF system. The basic search topics are listed in Table 2. Applicable documents were expanded through use of the references cited in the initial responses from the search. The total responses received from the STIF inquiries are listed at the bottom of Table 2. The responses which were pertinent to sewage treatment application are listed in Table 3. The most significant item is the Water Quality Monitor (NAS 1-10382) which is applicable in the rapid determination of organic loading and other criteria. The BIOSENSOR and the FLASH units may have application in the detection of sludge activity and monitoring of the sterilization process.

The Water Quality Monitor is described in an ASME manuscript of a presentation at the Environmental Control and Life Support Systems Conference, San Francisco, California, August 14-16, 1972.<sup>(1)</sup> This article presents the features of an instrument for assessing the potability of reclaimed water. The parameters that are measured by the Water Quality Monitor are: Ammonium ion ( $\text{NH}_4^+$ ), chloride ion ( $\text{Cl}^-$ ), pH, specific conductance, total organic carbon (TOC), and viable bacterial cell counts. The continuous flow sensing for organic carbon and viable bacteria cell count are unique features of this instrument which could be of use in a control system network.

A summary of the NASA-developed instruments identified through the technology search consisted of the following:

NASA-developed bacteria sensors: Various bacteria sensors were available, but not all would be of value to a control subsystem because of their time-consuming requirements and/or other practical limitations. Examples of these are the direct cell counting instruments employing microscopic counting chambers and the Coulter apparatus. Microscopic counting of bacteria is too tedious and time-consuming to be done routinely. The Coulter apparatus is sensitive to inert particulate matter as well as organisms. Table 4 presents comparative values of NASA-developed bacteria sensors.

**TABLE 2. TOPICS USED IN THE SEARCH OF NASA SCIENTIFIC AND TECHNICAL INFORMATION FACILITIES (STIF)**

- I. Bacteria (298 responses)
  - A. Detection of bacteria in:
    - 1. potable water
    - 2. sewage
    - 3. water
    - 4. liquids
  - B. Measurement of bacteria activity/inactivity
  - C. Detection of microorganisms in:
    - 1. potable water
    - 2. sewage
    - 3. water
    - 4. liquids
- II. Carbon Dioxide (CO<sub>2</sub>) (214 responses)
  - A. Measurement of carbon dioxide in:
    - 1. surface waters
    - 2. liquids
    - 3. gases
  - B. Measurement of rate of CO<sub>2</sub> production by bacteria
- III. Oxygen (O<sub>2</sub>) (184 responses)
  - A. Dissolved oxygen in H<sub>2</sub>O
  - B. Oxygen consumption rate measurements
- IV. Liquid Flow (50 responses)
  - A. Mass flow rate measurements
  - B. Density of fluids and suspensions
- V. Activated Sludge (135 responses)
  - A. Automatic control of sludge concentrations
  - B. Monitoring sludge densities

TABLE 3. SUMMARY OF NASA-DEVELOPED TECHNOLOGY PERTINENT TO THE  
AUTOMATIC CONTROL OF SEWAGE TREATMENT PLANTS

Technology or Device	NASA Source	Pertinent Unit Process	Process Control Function of Development	Accessory Equipment Requirements	State of Development
Bacteria Sensors	"BIOSENSOR" CP5083	Sterilization	The BIOSENSOR unit could provide a means to monitor the effectiveness of the sterilization process.	Output recorder and alarm	Prototype model
	"FLASH" CR411	Sludge recycle	The FLASH unit could be suitable as a measure of "Sludge Activity" for control of sludge recycle in proportion to incoming sewage organic load.	Signal integrator with flow and organic loading sensor and variable speed drives on sludge pumps	Prototype model (similar commercial units are available)
Carbon Dioxide & Oxygen Sensors	Multiple sources	Removal of dissolved organics (secondary treatment)	NASA technology has developed much information on oxygen and carbon dioxide and their measurement. Most equipment developments were miniaturizations of commercially available systems.	Signal output systems compatible with process control equipment	Needs development
Mass Flow & Sludge Density Meters	Multiple sources	Sedimentation, centrifugation, sludge pumping	NASA technology has provided circuitry improvements which have been adapted into commercial instruments such as ultrasonic, magnetic and gamma radiation flow meters and density meters.	Signal integrators with quality sensor to provide mass flow information for control of pumps, valves, etc.	Commercially available
Water Quality Monitors	NAS 1-10382	Sludge recycle, sterilization, effluent monitoring	This unit could function as a signal generator for organic loading (organic carbon), for effluent bacteria, pH, total dissolved solids (conductivity), ammonia, and chloride ions. The system includes sample feed and pretreatment apparatus (such as filters) and alarms and data readout.	Control mechanisms such as variable drive pumps, automatic valve operators, etc.	Prototype model

TABLE 4. COMPARATIVE VALUES OF NASA-DEVELOPED BACTERIA SENSORS<sup>1</sup>

Sensor	NASA Source	Type	Information	Amount or Rate per Organism	Amount or Rate Detectable	No. of Organism Required <sup>2</sup>	Time <sup>3</sup>
Wolf Trap	CR-56528	Growth	Viability in special growth media	Max. double each 15 min.	10 <sup>4</sup> bacteria/ml/mv	10	2-3 hr.
Gulliver	CR-60709	Metabolism	Specific substrate (Glucose-C <sup>14</sup> )	3.3 × 10 <sup>-3</sup> cmp/hr	25 CPM	10 <sup>3</sup>	1-2 hr.
Marbac	CR-62003	Metabolism	Viability in special growth media	not available	varied with differing combination	not available	not available
ATP-firefly Flash	CR-411 Brief 71-10055	Coenzyme	Living and dead particles	10 <sup>-9</sup> μG	10 <sup>-4</sup> μG	10 <sup>5</sup>	1 min <sup>4</sup>
Biosensor	Document No. CP5083	Staining morphology	Bacteria	1 Bacterium	20 Bacteria	20	5 min.

<sup>1</sup> Consists of an expansion of information listed in Table 3 of an article by Mitz, M.A., "The Detection of Bacteria and Viruses in Liquids", Annals of New York Academy of Science, Vol. 158, pp. 651-664.

<sup>2</sup> These values are the most optimistic values at present. One or two orders of magnitude higher are readily measured. Three approaches are still under investigation and further improvements are possible in most cases either in methodology or instrumentation.

<sup>3</sup> Time can be reduced in many cases if a large number of organisms is measured.

<sup>4</sup> Sample preparation of 13 to 27-1/2 minutes required in order to obtain a measurement of the living bacteria only.

The most promising of these instruments for use in sewage treatment were the BIOSENSOR and the FLASH unit. The BIOSENSOR involves the electronic scanning of collected samples using special microscopic optics. Specific staining enhances the ease of detecting and accurate counting of the organisms in the sample. The FLASH (Fast Luciferase Automated Assay of Specimens for Hospitals) unit also has a high potential for use as a bacteria monitoring tool.

A commercial instrument, based on ATP-bioluminescent reaction, is available from SRB, Inc., P. O. Box 1393, La Jolla, California 92036. A fast (sample preparation 5 min., assay time 1 min.) detection of live organisms only is reported.

NASA oxygen and carbon dioxide sensors: Oxygen and carbon dioxide detectors developed for NASA consist of miniaturizations of commercially available instruments. Certain unique methods of detection have been developed through NASA technology but are very specific and would not be applicable for development of the control center required for this program.

Mass flow measurements in liquids and sludge concentration or density measurements: Evaluation of the references cited for these two search topics indicated that the reported systems would not be applicable to this program. The majority of the technical reports cited dealt extensively with compressible fluids, cryogenic "slushes", and liquid propellants. Some highly sophisticated monitors have been developed for NASA application, but none were found to be applicable for the proposed control system. A commercially available sludge density meter which uses a gamma radiation technique as the detection principle has been available for use in sewage treatment plants for several years. It has been greatly improved through recent circuit design modifications resulting from NASA application of the system principles for space use.

Industrial Technology Search. --A survey was made, also, of industrial technology applicable to the automatic control of sewage treatment plants. Information was developed from current advertising literature and contacts with instrument and process control manufacturers. Water treatment processes have been automated for many years. This field was especially fruitful for process control systems which are directly transferable to the automation of wastewater treatment plants. These systems incorporate such sensors as pH, turbidity, conductivity, flow rate, differential pressure, etc. for the automatic process control of chemical feed, sludge blowdown, ion exchange regeneration and filter backwashing.

Table 5 is a listing of the commercially available process control systems which were found that are applicable to the automation of sewage treatment plants. The data in Table 5 are arrayed by "control parameter"

and "pertinent unit process" and by existing and future process control function of the parameter. Accessory equipment requirements and approximate costs of the various control systems are also listed in Table 5.

The lack of process control in state-of-the-art sewage treatment plant design is clearly shown in Table 5. The only parameter which has been widely used for real-time process control is "chlorine residual" which is used to monitor and/or control chlorine dosage rates. The other parameters in Table 5 which have been used in a control function are Dissolved Oxygen and Sludge Density. Other parameters may be recorded continuously, such as flow rates, or analyzed intermittently, such as Carbon and Oxygen Demand, but no use has been made of these in a control function. One example of real process control is the new sewage treatment plant for Atlanta, Georgia, which has recently been reported in the literature as an automated plant<sup>(2)</sup>. This automation consists of extensive monitoring, data recording, and automatic process control of screen cleaning, waste sludge pumpage, air blowers, centrifuges, and digesters.

### Conceptual Design

Formulation of Control Concepts. -- Work in this task consisted of the formulation of concepts for the automatic control of sewage treatment processes. The sewage model for these concepts was a flow of 35 million gallons per day of domestic sewage. The treatment model or scheme consisted of:

- Suspended solids removal,
- Dissolved organic solids removal,
- Dissolved inorganic solids removal,
- Effluent treatment--disinfection, and
- Sludge removal.

A listing was made of the various unit processes which are used to perform the tasks defined in the treatment model. A breakdown was then made of each unit process as to its purpose, the type of equipment used, operating problems experienced, and the process variables and parameters which are, or could be used to describe the process. This listing is shown in Table 6. The information from Table 6 was combined with that listed in Tables 4 and 5, and a selection was made of the process parameter and process control variable to be used for each unit process. These selections were used to provide a schematic drawing of the control concepts. This general control schematic is shown in Figure 2.

The NASA-developed Water Quality Monitor is the heart of the process control concept shown in Figure 2. The main control concept consists of a



**TABLE 5. COMMERCIALLY AVAILABLE<sup>1</sup> PROCESS CONTROL INSTRUMENTS SYSTEMS APPLICABLE TO THE AUTOMATION OF SEWAGE TREATMENT PLANTS--Continued**

Control Parameter	Pertinent Unit Process	Process Control Function of Parameter		Accessory Equipment Requirements	Approx. Installed Cost <sup>2</sup> of Instrument System
		Now in Use	Future Possibilities		
Flow Ratio Controllers	Sludge Recycle	Rarely used	Could be used to proportion sludge recycle flow in a constant proportion to raw sewage flow rate.	Flow rate sensors on raw sewage and sludge recycle and variable speed sludge pumps.	\$ 8,000
Oxygen Demand (TOD and COD)	Removal of dissolved organics (secondary treatment)	For monitoring of plant influent and effluent	Could be used in place of DOC as a measure of loading on the plant but does not differentiate between organic and inorganic oxygen requirements.	Flow rate sensors and sludge activity sensor with variable speed drive on sludge recycle pump.	Needs development
Oxygen Demand (TOD and COD)	Sterilization	Rarely used	May be used to determine the initial chlorine or ozone dosage requirement.	Integration with a flow rate sensor to give mass flow of oxygen demand	\$20,000
pH	Aeration	None	Could be a process control mechanism on aeration rate as mixed liquor pH reflects the equilibrium point between CO <sub>2</sub> removal rate and CO <sub>2</sub> production rate.	Control system on air flow rate	Needs development
pH	Sedimentation	None	Might provide a mechanism to maintain sludge removal at a rate to prevent gasification of the sludge.	Variable speed drive on sludge removal mechanism and sludge pumps	Needs development
Sludge Density	Primary Sedimentation	Rarely used to control density of waste sludge charged to anaerobic digesters	Could be used to control wastage rate of activated sludge based on ratio between sludge activity and sludge density	Sludge activity rate sensor and variable rate or time increment drive on waste sludge pumps	\$ 6,000
Sludge Density	Final Sedimentation	None	Could be used to control sludge removal rate from final clarifier	Variable speed drive on sludge removal mechanism and sludge pumps, and/or a flow control valve	\$ 6,000
Turbidity	Final Sedimentation	None	Could be used to locate sludge interface level in final clarifier and to control sludge withdrawal rate	Variable speed drive on sludge removal mechanism and sludge pumps, and/or flow control valve	\$ 3,000

<sup>1</sup>"Commercially Available" is defined as an instrument package offered by two or more manufacturers.

<sup>2</sup>Cost of the instrument system does not include cost of the accessory equipment such as flow control valves or variable speed pump drives.

<sup>3</sup>DOC--Dissolved Organic Carbon.

**TABLE 5. COMMERCIALLY AVAILABLE<sup>1</sup> PROCESS CONTROL INSTRUMENTS SYSTEMS APPLICABLE TO THE AUTOMATION OF SEWAGE TREATMENT PLANTS--Concluded**

Control Parameter	Pertinent Unit Process	Process Control Function of Parameter		Accessory Equipment Requirements	Approx. Installed Cost <sup>2</sup> of Instrument System
		Now in Use	Future Possibilities		
Dissolved Oxygen	Sedimentation	None	Could provide a sensitive means to control sludge removal rate from final clarifiers	Variable speed drive on sludge removal mechanisms (scraper drive and sludge pump).	\$ 4,000
Dissolved Oxygen Uptake Rate	Removal of dissolved organics (secondary treatment)	Experimental	Could provide a measure of "sludge activity rate" for controlling sludge recycle.	Sludge flow rate sensor for integration of signals, sewage flow and strength sensors, and variable speed drive on sludge pump	Needs development
Flow Rate	Important to all unit processes	Flow rate of sewage, air, recycle sludge, etc. is usually monitored and recorded.	Integration of flow information with analytical parameters will provide information suitable to the control of many plant processes.	Primary flow device (such as Parshall flume) and associated analytical equipment and flow control devices.	\$1,000 to \$10,000 each, depending on type of flow meter and application
Bacteria Sensors	Aerobic and Anaerobic Processes and Sterilization	Mostly used in experimental and research work	ATP or bioluminescence might serve for "sludge activity" and for control of sterilization process	Flow sensors and variable speed drive on sludge pumps or automatic chlorinator	Needs development
Carbon	Removal of dissolved organics (secondary treatment)	Experimental and monitoring	To measure organic loading as DOC <sup>3</sup> and proportion recycle sludge in constant ratio	Flow rate sensors and sludge activity sensor with variable speed drive on sludge recycle pump	\$20,000
Carbon	Lime coagulation	None	To control lime feed rate to maintain a minimum inorganic carbon concentration (alkalinity)	Automatic drive unit on lime feeder	\$15,000
Carbon Dioxide	Removal of dissolved organics (secondary treatment)	None	Would provide a means for determining "sludge activity rate" for controlling sludge recycle and sludge wastage rates	Flow sensors, sewage strength sensors, signal integrators and variable speed drives on sludge pumps	\$30,000
Chlorine Residual	Sterilization	To control chlorine dosage rate to maintain set residual	To feed a second chlorine dosage midpoint in contact basin with original dosage controlled by flow	Automatic chlorinator	\$15,000
Differential Level	Screening	Rarely used	To provide an alarm on screen clogging by measuring the head loss across the screen	None	\$ 1,500
Dissolved Oxygen	Aeration	D.O. is sometimes monitored continuously, seldom used in a control function	Could be used to regulate air flow to aeration basins if oxygen transfer were limiting rather than mixing	Flow control valves in air line or means to turn blowers "on" and "off"	\$ 5,000

**TABLE 6. OUTLINE OF VARIOUS SEWAGE TREATMENT  
PLANT UNIT PROCESSES**

Unit Process	Purpose	Equipment Description	Operating Problems	Process Parameters
Screening and Grinding	The removal or reduction in size of coarse solids (rags, sticks, etc.) to protect plant equipment.	Bar screens, mechanical screens, comminutors	Cleaning of screens, breakage, corrosion, handling and disposal of screenings, odor, flies.	Differential head across screen, torque limit on cutters and mechanical linkage, rate of screenings removal, heat value and water content of screenings
Grit Removal	The removal of inorganic sand and grit to protect plant pumps, piping, clarifier scrapers, and sludge digesters.	Flow channels which may be mechanically or manually cleaned—flight conveyors, bucket elevators, reciprocating rakes, turbine mixers for controlled velocity.	Erosion of metal surfaces and bearing wear, poor washing of organics from grit leading to odor and flies, manual disposal (usually buried).	Flow velocity in separating channel, rate of grit accumulation, grit density, water content.
Primary Sedimentation	The removal of floating and settleable matter, mostly organic solids and grease.	Circular or rectangular tanks are used with bottom scrapers and top skimmers. Baffle plates at weir overflow trap floating scum for removal by skimmer.	Settleable solids gasify and rise to release odors and carry over solids. Process is inefficient and subject to upset by rapid changes in water temperature and/or wind action.	Overflow rate, sludge and scum accumulation rates, temperature rate of change, solids removal, nutrient and dissolved organics, pH, sulfides.
Flow Measurement	To indicate, record and integrate plant flow rate, sludge recycle rate, waste sludge rate, supernatant return rate.	Primary flow measurement system is normally a Parshall flume. Flow tubes and magnetic meters are also used.	Blockage of piezometric openings by solids, corrosion of metal elements by acid gases, operating personnel not trained for service.	Instantaneous flow rate and time-integrated flow volume.
Aeration and Activated Sludge Recycle	To remove dissolved organics from the waste water. Also serves as a biological floc to remove colloids.	Several flow schemes exist, but all utilize a mass culture of microorganisms and entrained organic and inorganic material (activated sludge) which is continuously refluxed with the primary effluent and aerated for a period of time (6 to 24 hours). The sludge is then removed from the through-flow by sedimentation and returned for another aeration cycle.	Variation in flow, retention time, food/culture ratio (loading), etc. lead to such problems as: sludge bulking, population take-over, activity loss. Maintenance on aerators, blowers, and air diffusers is a continuous problem.	Biochemical oxygen demand (BOD), mixed liquor suspended solids (MLSS) and volatile suspended solids (MLVSS), sludge volume or density index (SVI, SDI), pH, dissolved oxygen (D.O.), dissolved organic carbon (DOC).
Final Sedimentation	To separate suspended solids (activated sludge) from the through-flow for recycle to the aeration tanks.	Rectangular and circular sedimentation tanks are used with bottom scrapers for sludge removal to sumps from which it is discharged by static head. Occasionally, displacement type pipe arms are used for sludge removal.	Sludge bulking (poor settling characteristics of floc) lead to carryover. Long retention in final clarifier leads to gasifying and flotation of sludge solids. Thermal density and wind currents affect this separation process.	Suspended solids, turbidity, sludge level, dissolved oxygen, settling rate, surface loading rate, sludge removal rate and sludge density.
Disinfection	To "kill" residual pathogenic organisms in plant effluent	Usually a plug-flow type contact chamber is used to provide reaction time with the disinfecting agent. Chlorine gas is used in large plants, while hypochlorite is used in smaller plants. Ozone is used sometimes.	Maintaining the required residual is difficult because of inability to predict chlorine demand and lag time of reactions. Bacteria measurement methods require days for analysis and data feedback.	Cl <sub>2</sub> residual, Cl <sub>2</sub> demand, bacteria plate count, MPN (most probable number of coliform bacteria/100ml).

means to recycle sludge flow rate in proportion to the mass inflow rate of dissolved organics. This is done with two sets of signals. The first set constitutes the process parameter--"Mass Flow of DOC", and the second set represents the parameter "Active Mass Flow of Recycle Sludge". These two signal sets are opposed through a controller whose output signal operates a slide gate which controls recycle sludge flow rate. The controller compares the two signal sets and will change the sludge recycle flow control gate until the signals are in balance. Thus, the control concept shown in Figure 2 describes a new approach to controlling the activated sludge process, namely, control of the activated sludge recycle rate in a manner which will maintain a consistent ratio between the incoming food and the active mass of recycled sludge. The NASA Water Quality Monitor is a significant advance towards this goal. The electronics package associated with this instrument's TOC analyzer is especially significant because its signal output is directly proportional to DOC (dissolved organic carbon). It is this DOC signal which, when integrated with sewage flow rate, will provide the mass rate of flow signal which constitutes the food loading.

Incorporation of the flow and process control scheme of Figure 2 into an existing plant could possibly increase the plant's capacity without the addition of new aeration basins. Assuming such a control scheme could double the capacity of a 35 Mgd sewage treatment plant, the savings in capital investment on the aeration basins alone would be several million dollars. In addition, over 500 hp of energy would be saved in compressing air for mixing the aeration basins, because only half as much basin volume would need to be mixed. Thus, an expenditure estimated at several hundred thousand dollars for controls could be justified by the savings in capital investment and power costs. In addition, the automated plant could possibly produce a more consistent and higher quality effluent at lower manpower requirements than do existing plants.

Application of the Automatic Control Concept for Expansion of an Existing Treatment Facility. --Some of the concepts shown in Figure 2 consist of process improvements such as use of the waste digester gas to dry and, possibly, incinerate the organics removed in the screening and grit removal processes. Such use would eliminate an intense fly and odor problem at many sewage treatment facilities.

One instrument development important to the process control concept is the carbon analyzer. Although existing instruments are far from perfect, the carbon analyzer is especially suited to the description and control of biological processes. Carbon is the basic building block of biological systems and constitutes both the primary food requirement and the major fraction of cell protoplasm. Carbon is involved in all three phases (solid, liquid, gas)

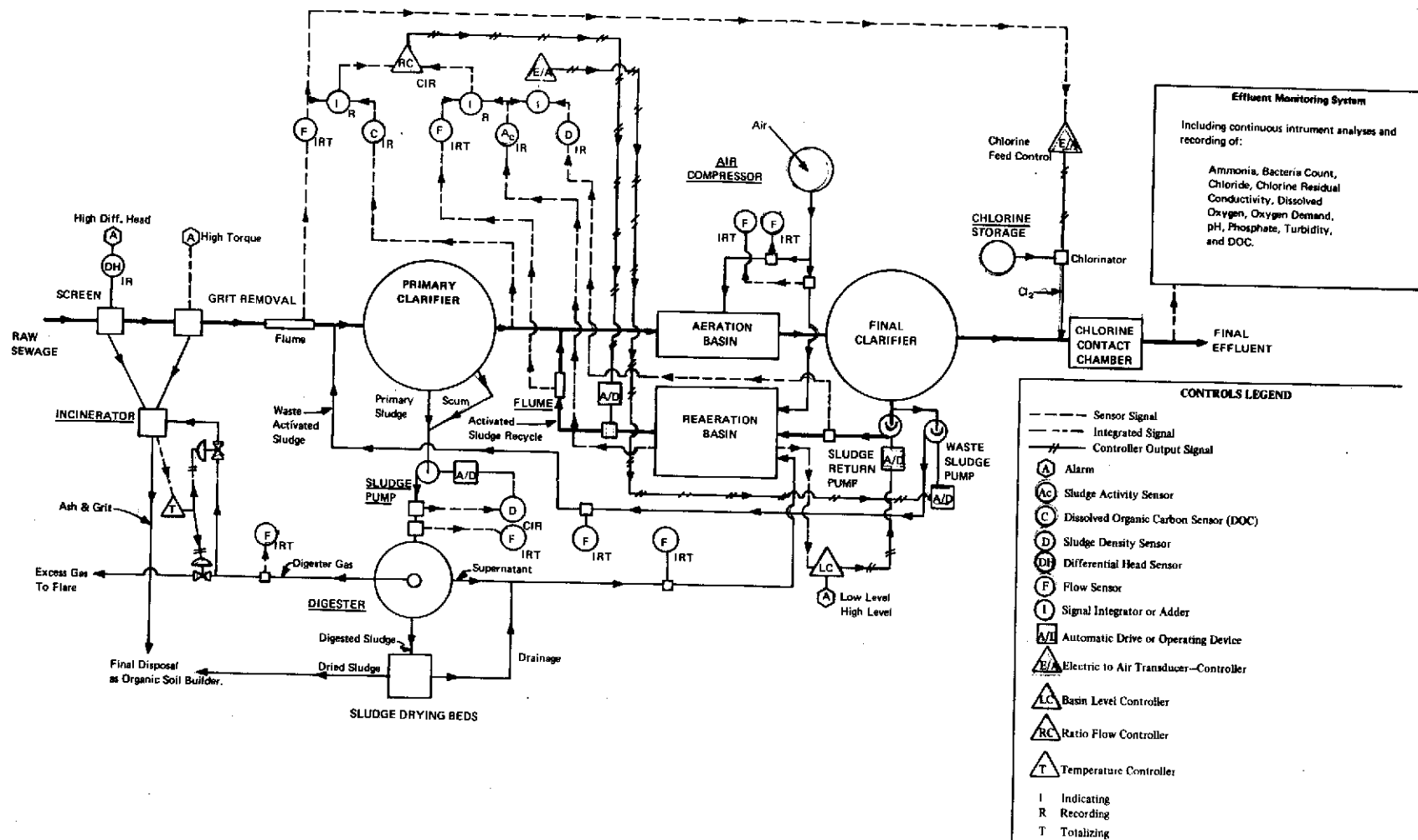


FIGURE 2. AUTOMATIC CONTROL CONCEPT FOR A SEWAGE TREATMENT PLANT - ACTIVATED SLUDGE PROCESS

of biological systems and is continually being changed from one phase to another by such systems. Thus, carbon should be an invaluable parameter for defining the stoichiometry and kinetics of biological systems. However, the potential of this instrument for process control has been limited.

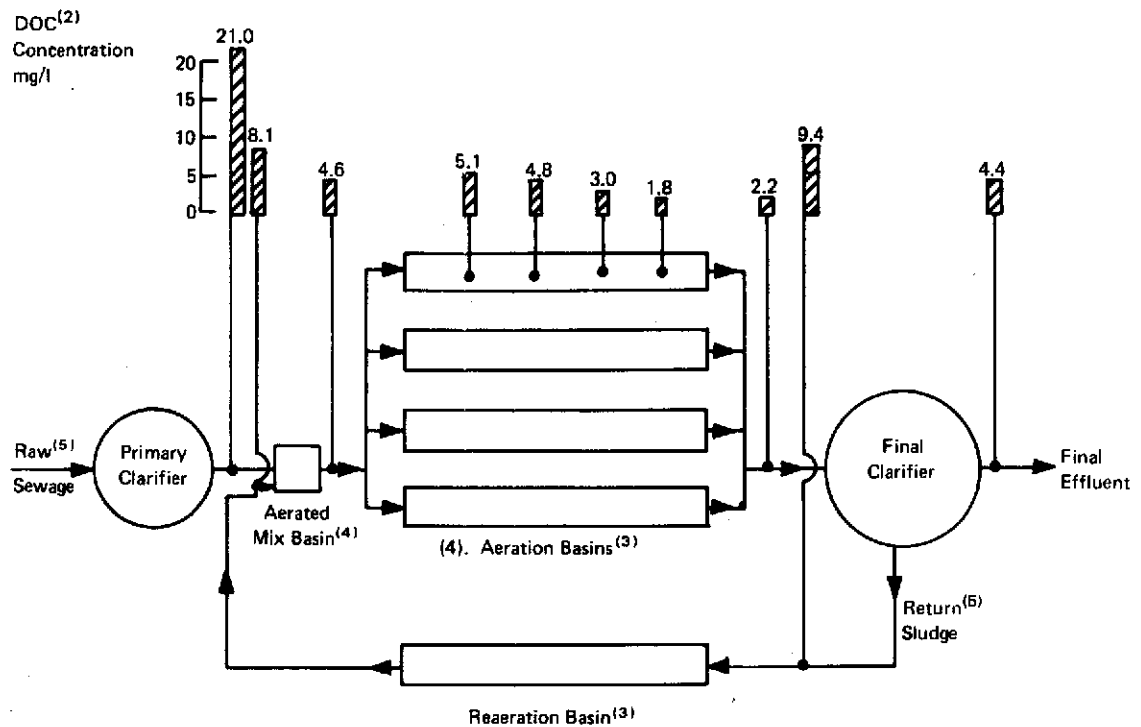
Application of carbon analysis to the process control of biological treatment plants is done quite easily. In this use, it is important to differentiate between the dissolved organic carbon (DOC) and the suspended organic carbon (SOC) fractions of the system. If we look upon biological treatment as a unit process for the removal of dissolved organics, it is immediately obvious that an instrument which provides real-time data on that parameter can be used to determine such important control criteria as:

Inlet DOC concentration and mass flow rate of microbial food,  
End-point DOC concentration (refractory) of the effluent, and  
Growth rate and yield.

There are several carbon analyzers which would be suitable, with some modification, for this application. The NASA Water Quality Monitor has already incorporated most of these needed changes. This instrument could thus be used to maintain nearly constant loading conditions of food to active sludge mass. This would be a radical change from present operational modes. It is probable that this type control would produce a consistently high effluent quality in a considerably shorter retention time than is now being obtained from conventional plants. It is also probable that such control would greatly reduce "sludge bulking" and similar process problems.

The advantages of a process control system for sludge recycle are illustrated by a series of analyses which were made on a typical activated sludge plant. These analyses were made to determine the progression of dissolved organic carbon (DOC) through the aeration basins. Results of these analyses (averages of 10 sets of data) and sample point locations are shown in Figure 3. The major fraction of DOC was removed very rapidly upon mixing the primary sewage with the recycled sludge. In fact, the DOC of the mixing basin effluent was within 3 mg/l of the DOC of the aeration basin effluent. Average DOC removal through the mixing basin was 16.4 mg/l with a detention time of less than 15 minutes. Additional DOC removal through the aeration basins was only 2.4 mg/l even though an additional retention time of 6.6 hours had been provided in the aeration basins.

In effect, these data indicate that the sewage might by-pass the aeration basins and go directly to the final clarifier from the aerated mixing basin. This change would probably require additional retention time for sludge reaeration to allow an equivalent growth period for the protozoans in the activated sludge. Use of just one of the four by-passed aeration basins would



NOTES:

- (1) Leon Creek Sewage Treatment Plant, San Antonio, Texas.
- (2) DOC-Dissolved Organic Carbon determined on a sample after filtration through a membrane filter (0.45 $\mu$  pore size). Average of 10 sample sets.
- (3) Aeration and Reaeration Basins are 30 ft wide X 300 ft long X 14 ft deep.
- (4) Mix Basin is 45 ft square X 9 ft deep.
- (5) Raw Sewage flow rate during sample period—10.9 MGD Avg.  
Return Sludge flow rate during sample period—2.7 MGD Avg.

FIGURE 3. DISSOLVED ORGANIC CARBON (DOC) PROGRESSION  
THROUGH AN ACTIVATED SLUDGE SEWAGE  
TREATMENT PLANT<sup>(1)</sup>

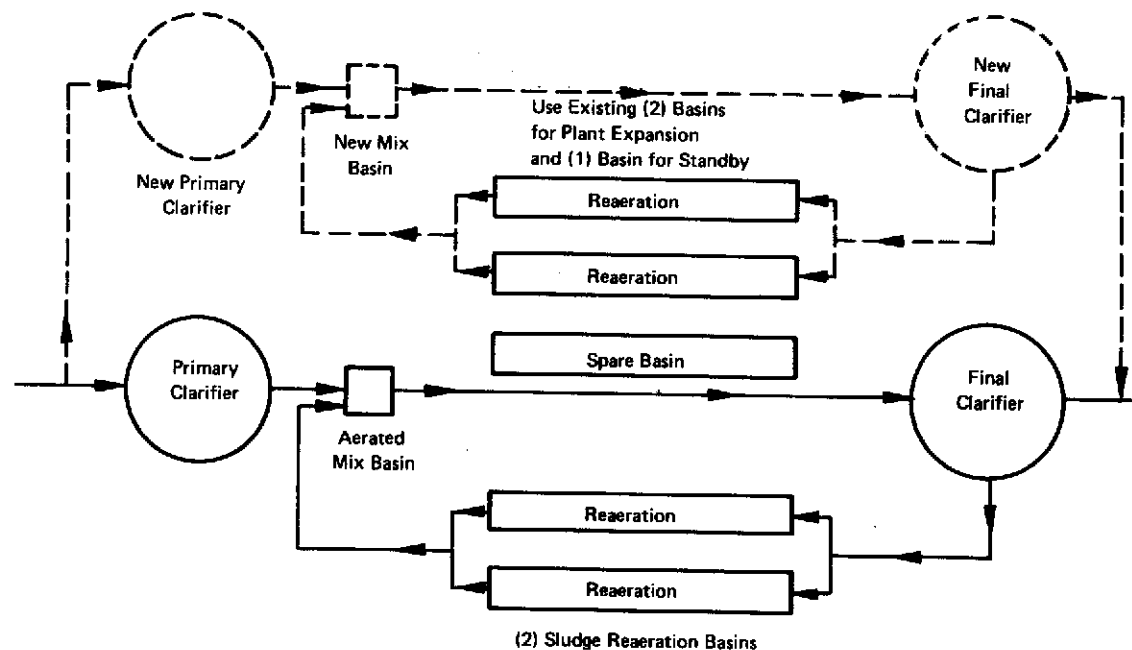
be sufficient for this purpose. Thus, three of the existing aeration basins at this plant could be taken out of service, and total air consumption (and power requirement) would be cut in half. This proposed flow scheme is shown in Figure 4. Also shown on Figure 4 are the additions which would be necessary to possibly double the plant capacity. Note that only a new primary and final clarifier and a new mixing basin are required for this expansion. Use of the existing aeration basins and air compressors for sludge reaeration basins will halve the cost of such an expansion.

Actually, this flow scheme has been used previously but has not found wide acceptance because it has not produced a consistent high quality effluent. Obviously, an automatic process control scheme is essential to the successful operation of the suggested system because the small volume and short retention time of the mixing basin do not allow room for error. A means is needed to proportion, automatically, sludge recycle rate with the mass inflow of dissolved organics. In this way, the reaction time for removal of these organics can be made to coincide with retention time of the reaction basin. The control concept shown in Figure 2 contains the basic elements to provide such a control system.

Evaluation of the NASA Water Quality Monitor. --The carbon analyzer system of the NASA Water Quality Monitor was evaluated in the Institute's laboratory to determine its suitability to the control concept. The timing mechanism of the instrument was increased from its original 30-minute cycle to a 6-minute cycle. The shorter cycle is desirable for process control purposes. However, the Water Quality Monitor as now designed, was found to have a significant problem in its accuracy and sensitivity. The unit was giving very erratic results, and the reason was traced to the sample injection system. Injection valves with sample loops are used in the Water Quality Monitor for injection of sample aliquots into the Total Carbon and Inorganic Carbon furnaces. Upon injection, these sample loops are swept with a carrier gas, and the samples are forced into the respective furnaces through injection needles. However, a variable and significant fraction of the sample was found to cling to the end of the injection needle on each injection. The analysis of a constant volume of sample is necessary to both the accuracy and precision of this instrument. This fault can be corrected and does not distract from the suitability of the Water Quality Monitor for use in the process control concept. No further evaluation of the TOC system was deemed necessary as considerable work has been published on modifications to the specific TOC analyzer used in the Water Quality Monitor<sup>(3)</sup> and the application of carbon analyses to biological systems<sup>(4)</sup>.

Sludge Activity Sensor. --The carbon dioxide production rate of the recycled sludge was selected as the optimum "activity" sensor. The most straightforward approach to applying the CO<sub>2</sub>-Activity Sensor is to trap a side-stream of off-gas from the reaeration basin at the outlet end. This gas sample





**CASE I. Existing Plant Conversion (shown in solid line)**

- Convert (1) aeration basin to sludge reaeration basin for a total of (2) reaeration basins.
- Take (3) aeration basins and (1) 350 HP blower out of service (1 blower in service, 2 standby).
- Install line from mixing basin direct to final clarifier.
- Install process control system for sludge recycle.

**CASE II. Plant Expansion to Possibly Double Capacity (shown in dashed line)**

- Install new Primary and Final Clarifiers and new Mix Basin.
- Connect (2) out-of-service aeration basins into system and use (2) blowers ((1) blower and (1) basin for standby).
- Install process control system for sludge recycle.

**FIGURE 4. SUGGESTED CONVERSION AND/OR EXPANSION OF SEWAGE TREATMENT PLANT USING PROCESS CONTROL ON SLUDGE RECYCLE**

is passed in a continuous flow through a non-dispersive infrared analyzer for CO<sub>2</sub> analysis. The more biologically active the sludge, the higher will be the CO<sub>2</sub> content of the off-gas. This same activity sensor will be used in conjunction with sludge density to control sludge wastage. This control will be set to increase the discharge of waste sludge as "activity" decreases or density increases, and to decrease sludge wastage as sludge "activity" increases or density decreases. In this manner, a sludge of relatively constant activity and density should be maintained. Other candidate sensors which were considered for the definition of sludge activity are "oxygen uptake rate" and "viable ATP". Either of these may prove to be superior to CO<sub>2</sub> production rate as the "activity" sensor.

### Preliminary Design

Subsystem Layouts. -- The schematic process control diagram of Figure 2 was expanded to provide a preliminary design of the selected controls system. These preliminary designs are shown in Figures 5, 6, 7, and 8.

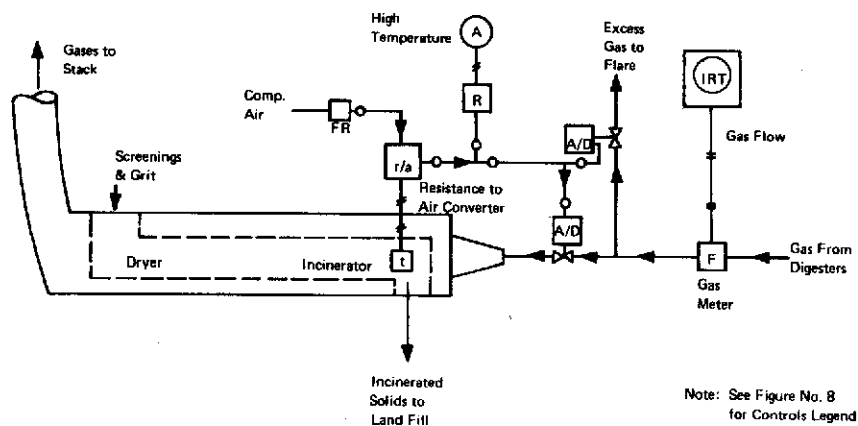
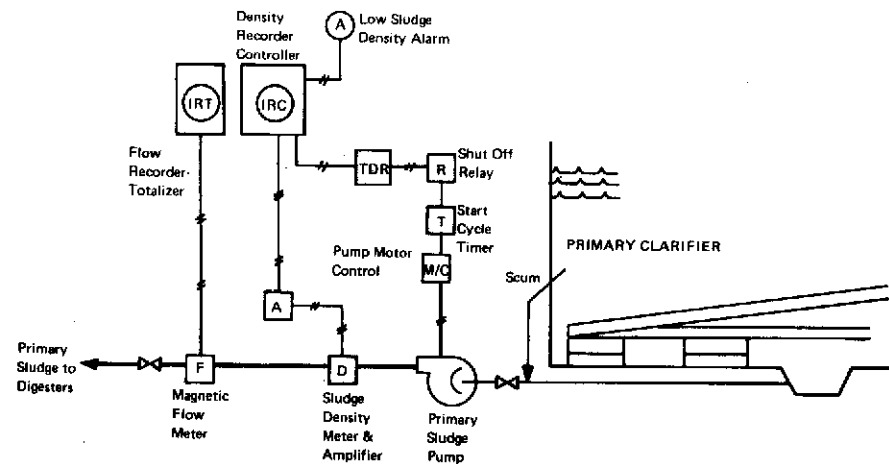
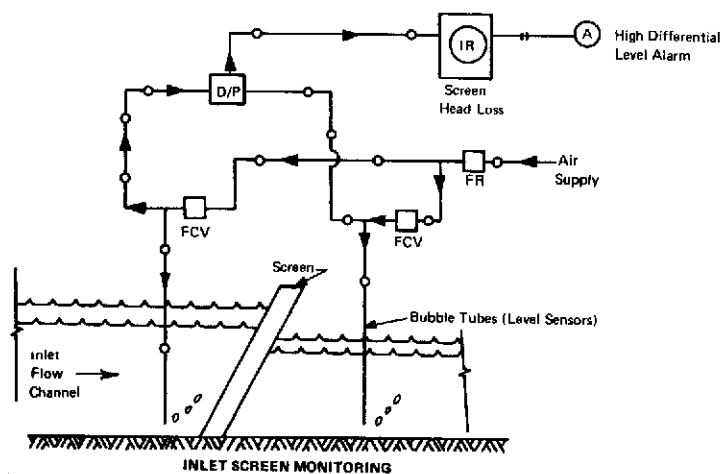
The sensor and sampling locations, the process controls circuits, general electrical circuits, and instrumentation of the subsystems are all shown on these same figures. A legend is shown on Figure 8 which explains the functions of the process control items used in these preliminary designs. A discussion follows of the input and output data and automatic features of the controls system.

#### Controls Description. --

Screen controls - ref. Fig. No. 5: Since channel design of headworks is normally such as to maintain relatively constant velocity through the screen, differential head (head loss) across the screen should be constant, regardless of flow. Therefore, screen head loss is a measure of screen resistance or cleanliness. The instrumentation system proposed will record screen head loss and will provide an alarm to instigate emergency cleaning procedures.

Grit remover controls - ref. Fig. No. 5: Grit removal equipment is designed for continuous operation. In the event a peak grit load piles up to the extent that the high torque switch trips to stop the drive unit, an alarm is sounded to start emergency action.

Screenings and grit dryer-incinerator controls - ref. Fig. No. 5: This is a new unit process addition to utilize digester gases to dry and burn screenings and grit. Controls will consist of standard combustion controls and gas diversion device in the event of flame-out. Gas will be



Note: See Figure No. 8  
for Controls Legend

FIGURE 5. PRELIMINARY SUBSYSTEM LAYOUT - SCREENING, INCINERATION, AND PRIMARY SEDIMENTATION

FIGURE 6. PRELIMINARY SUBSYSTEM LAYOUT - ACTIVATED  
SLUDGE RECYCLE CONTROLS

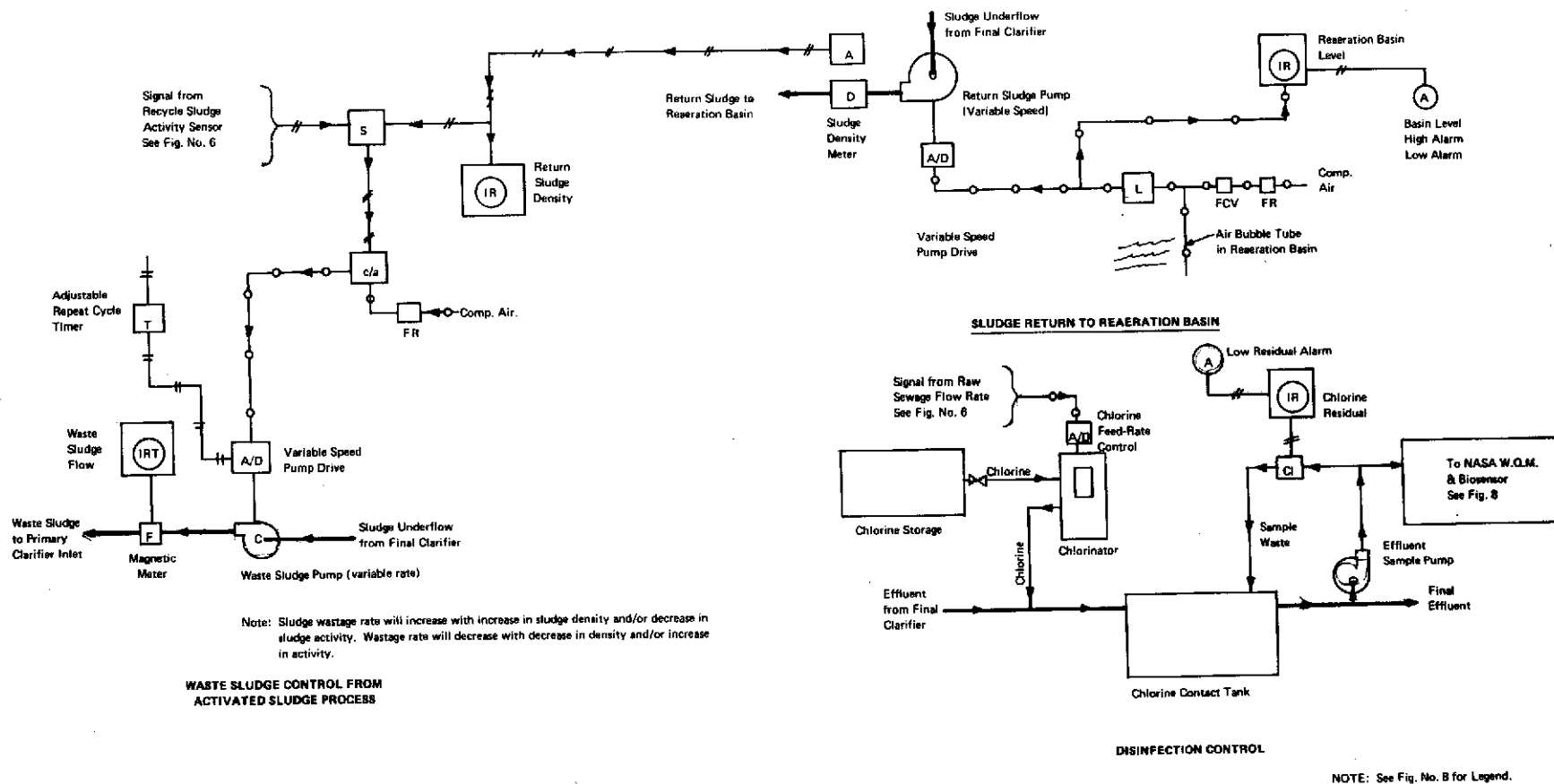


FIGURE 7. PRELIMINARY SUBSYSTEM LAYOUT - SLUDGE WASTAGE, SLUDGE RETURN, AND DISINFECTION

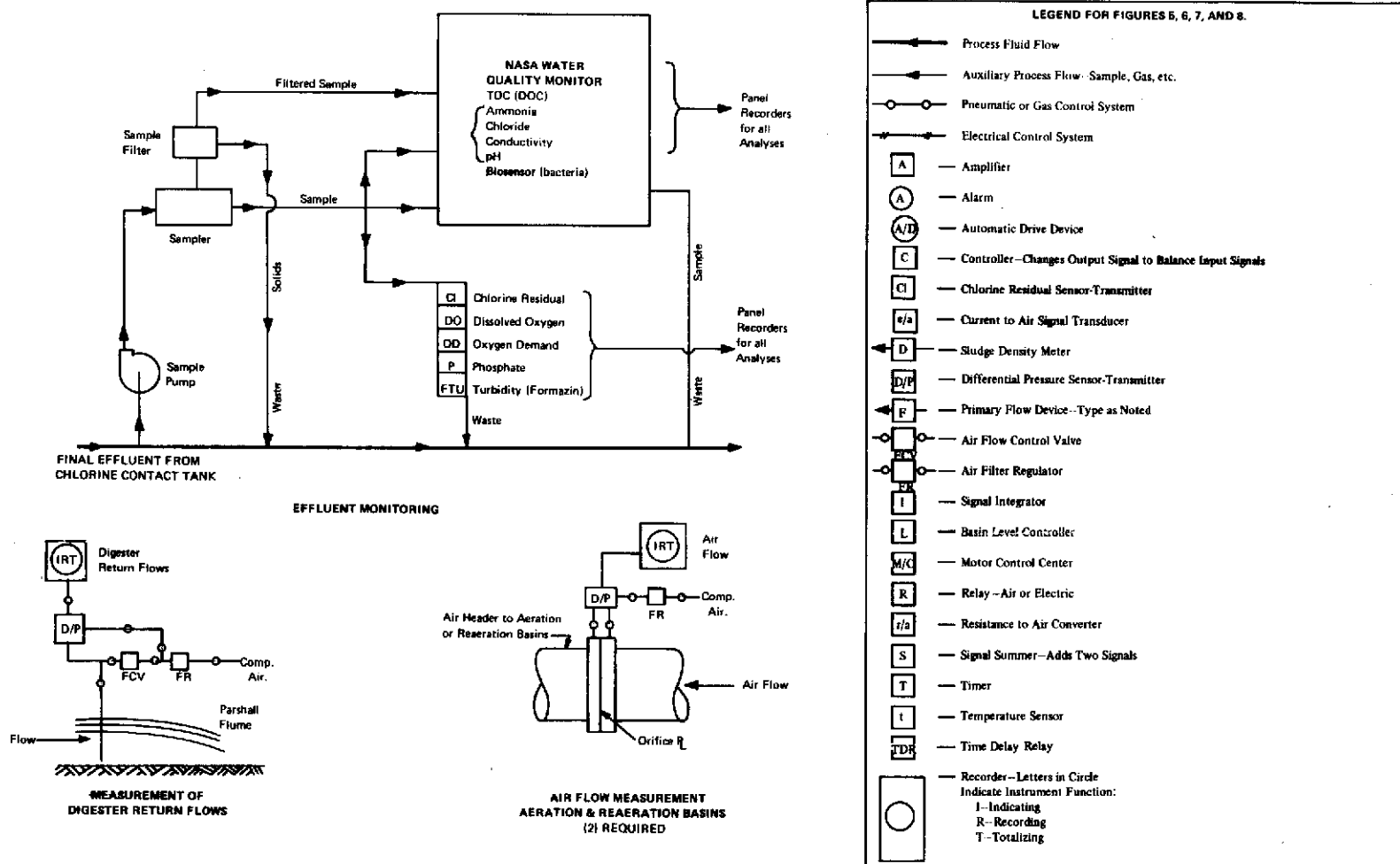


FIGURE 8. PRELIMINARY SUBSYSTEM LAYOUT - EFFLUENT MONITORING, AIR AND GAS FLOW METERING, AND LEGEND

diverted to a flare when incinerator fire is out. Temperature of the incinerator will control gas firing rate.

Primary sedimentation controls - ref. Fig. No. 5: Sludge pumpage to digesters will be controlled by a sludge density meter. This pump will be turned "on" by a repeat cycle timer and will be turned "off" by a low density signal from the sludge density meter. A time delay relay is inserted in the density meter signal to prevent immediate shut-off after pump start-up. Sludge flow will be measured with a magnetic meter, and both flow and density of the primary sludge will be recorded. A low density alarm will be provided which will signal failure of the pump to turn "off".

Activated sludge recycle controls - ref. Fig. No. 6: The recycle of activated (reaerated) sludge will be made in a manner to provide a constant ratio between the mass of incoming food and the active mass of recycled sludge. This will be done by a controller which will operate a channel slide gate to increase or decrease the recycled sludge flow rate, as necessary, to balance two signals. The first signal will represent the mass flow of incoming food and will be obtained by multiplying the raw sewage flow signal by the DOC signal. The second, opposing, signal will be obtained by multiplying the recycled sludge flow signal by the "activity" signal of the sludge. Records will be kept of the sewage and sludge flow rates, the integrated mass flow and activity mass flow signals, DOC concentration, and sludge "activity" level. Alarm systems will be provided for high DOC, high sewage flow rate, and excessive out-of-balance of controller input signals.

Sludge return controls - ref. Fig. No. 7: As sludge recycle rate changes, a proportional change must also be made in the rate of return of sludge underflow from the final clarifier. Return rate will be kept in equilibrium with recycle rate by a basin level control in the reaeration basin and a variable speed drive on the return sludge pump. Decreasing basin level will increase pump speed and vice versa. Basin level will be recorded, and high and low level alarms will be provided.

Activated sludge wastage control - ref. Fig. No. 7: It is necessary to waste sludge from the activated sludge system to prevent the buildup of inert materials and to compensate for biological growth and accumulations. Sludge wastage will be done in a manner to maintain a stable sludge of constant quality. A sludge density meter will be provided on the return sludge line; the signal from this density meter and the sludge "activity" signal will be summed in a manner such that increasing density and/or decreasing activity will increase the output signal, and vice versa. This output signal will operate the variable speed

drive on the waste sludge pump. This pump will be turned "on" and "off" by an adjustable repeat cycle timer but pump rate during "on" time will be a function of the sludge density-activity control.

Disinfection control - ref. Fig. No. 7: It is expected that the automated activated sludge system will provide an effluent of sufficiently constant quality that chlorine feed control by sewage flow rate will be adequate. A chlorine residual sensor, recorder, and low residual alarm will be provided (see Figure 8) to assist in manually setting the chlorine dosage level.

Effluent monitoring - ref. Fig. No. 8: The NASA Water Quality Monitor and BIOSENSOR will be used to provide continuous monitoring of effluent quality, including:

- ammonia ion,
- specific conductance,
- chloride ion,
- pH,
- TOC (DOC),
- viable bacteria, and
- total bacteria.

A duplicate TOC sensor will be necessary to monitor effluent carbon, because one unit is necessary for the process control of activated sludge.

In addition to the criteria noted above, chlorine residual will be monitored as shown in the disinfection controls. Other items of interest, which could be monitored with an instrument such as Technicon's Autoanalyzer, or flow-through cells, are orthophosphate, oxygen demand, dissolved oxygen, and turbidity.

## CONCLUSIONS

Conclusions which have resulted from this effort are as follows:

1. Municipal sewage treatment practices are almost completely void of even the crudest of instrumentation or process control technology.
2. Applicable control technology, sensors, and instrumentation are available commercially and from certain NASA developments to



automate and monitor many of the unit processes found in sewage treatment plants.

3. The NASA Water Quality Monitor is especially suited, with some modification, to provide the important function of DOC analysis in the process control system for Activated Sludge Recycle.

4. The NASA-developed BIOSENSOR and Water Quality Monitor are both suited to the continuous monitoring of the final effluent from automated sewage treatment plants.

5. Construction or expansion of municipal sewage treatment plants based upon the automatic control concept appears to effect sufficient savings in capital expenditures and power requirements to offset the cost of the control system.

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